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|  | EUROPEAN COMMISSIONDIRECTORATE-GENERAL ‘RESEARCH’ | INTERNATIONALSCIENCE ANDTECHNOLOGYCENTRE |  |

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## NON PROLIFERATION THROUGH SCIENCE AND CO-OPERATION

**CONTACT EXPERT GROUP**

**on**

**SEVERE ACCIDENT MANAGEMENT**

**(CEG-SAM)**

**MINUTES OF THE 16th MEETING**

**Nuclear Safety Institute of the Russian Academy of Science (IBRAE)**

**Moscow, Russian Federation**

**September 8-9, 2009**

Meeting Location: Conference room of IBRAE

Tul’skaya, 52, Moscow

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| Dissemination level: REPU: publicRE: restricted to EC and a group specified by the CEG-SAM membersCO: confidential, only for EC and CEG-SAM members |

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Final minutes, April 1, 2010 CEG-SAM / M-16

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| Subject: 16th Meeting of the ISTC/STCU “Contact Expert Group on Severe Accident Management” (CEG-SAM)Place: Conference room of IBRAE, Moscow, Russian FederationDate: September 8-9, 2009Participants: 40 participants of 24 organizations from 10 countries: Mr. G.Azarian AREVA NP, Paris Mr. D.Bottomley EC, JRC - ITU, Karlsruhe Mr. B.Clement IRSN, Cadarache Mr. A.Fargette AREVA NP, Erlangen Mr. S.Güntay PSI, Villigen Mr. L.E.Herranz CIEMAT, Madrid Mr. P.Hofmann Consultant, Karlsruhe (**secretary**) Mr. M.Hugon EC, DG-RTD / J.2, Brussels (**chairman**) Mr. Ch.Journeau CEA/DTN, Cadarache Mr. M.Krause AECL, Chalk River, Canada Mr. J.S.Lamy EdF, Clamart Ms. L.Nicolas CEA, Saclay Mr. F.Oriolo University, Pisa Mr. J.Stuckert FZK, Karlsruhe Mr. S.Bechta RIT-NITI, Sosnovy Bor Mr. A.Boldyrev IBRAE-RAS, Moscow Mr. V.Chudanov IBRAE-RAS, Moscow Ms. L.Degtyareva NPO LUCH, Podolsk Ms. V.Golovko ZAO “METR”, Moscow Mr. A.Gozal ISTC, Moscow Mr. W.Gudowski ISTC, Moscow Mr. A.Kisselev IBRAE-RAS, Moscow Mr. A.Kondrashenko VNIIEF, Sarov Ms. V.Kornyeyeva NSC KIPT, Kharkov Mr. V.Krasnov ISP NPP, Kiev Mr. V.Loktionov MPEI, Moscow Mr. V.Nalivaev NPO LUCH, Podolsk Mr. V.Pazhetnev OKB “GIDROPRESS”, Podolsk Mr. V.Semishkin OKB “GIDROPRESS”, Podolsk Mr. M.Sheindlin OIVT, Moscow Mr. V.Shestak IBRAE-RAS, Moscow Mr. A.Sorokin IPPE, Obninsk Mr. V.Strizhov IBRAE-RAS, Moscow Mr. D.Tomashchik IBRAE-RAS, Moscow Mr. M.Veshchunov IBRAE-RAS, Moscow Mr. E.Visotski ISP NPP, Slavutich Mr. S.Vorobiev ISTC, Moscow Ms. T.Yudina IBRAE-RAS, Moscow Ms. V.Zhdanov IAE NNC RK, Kurchatov-City Mr. V.Zhdanov IAE NNC RK, Kurchatov-CityDistribution list:(Shortened version Ms. M.Minch DG-RTD / Dof the minutes) Mr R.Burmanjer DG-RTD / D.3 Mr. J.Sanders DG-RTD / D.3 Mr. O.Quintana Trias DG-RTD / J Mr. A.Perez Sainz DG-RTD / J.1 Mr. A. Zurita DG-RTD / J.1 Mr. S.Webster DG-RTD / J.2 Mr. P.Manolatos DG-RTD / J.2 Mr. G.Van Goethem DG-RTD / J.2 Mr. R.Schenkel DG-JRC Mr. P.Frigola DG-JRC / 2 Mr. G.Sadler DG-JRC / 2 Intranet of Unit J.2 Mr. L.Tocheny ISTC, Moscow Mr. S.Vorobiev ISTC, Moscow Mr. W.Gudowski ISTC, Moscow Mr. A.Gozal ISTC, Moscow Mr. V. Stepanenko STCU, Kyiv EU CEG-SAM membersContact person: Mr. M. Hugon Tel.: +32 2 296 5719 – DG-RTD / J.2 |

Revised final agenda of the meeting see Annex 1, list of participants see Annex 2.

The Institute of Nuclear Safety of the Russian Academy of Science (IBRAE) organized the 16th CEG-SAM meeting in Moscow, Russian Federation, on September 8-9, 2009. The meeting location was the conference room of IBRAE.

The CEG-SAM meeting is divided into restricted and extended sessions. The restricted sessions are to discuss internal matters and the status of current ISTC/STCU projects. The extended sessions are dedicated to presentations of the progress of on-going ISTC/STCU projects and of new or revised ISTC/STCU proposals by scientists from the Russian Federation, the Republic of Kazakhstan and the Ukraine.

The chairman M.Hugon (EC) welcomed the CEG-SAM members. L.Tocheny (ISTC) and V.Stepanenko (STCU) apologized not to be able to attend the meeting. A. Gozal (ISTC) replaced L. Tocheny.

**Restricted session**

**Topic #1:** Welcome and opening remarks

The chairman M.Hugon opened the first part of the restricted session and welcomed the EU participants of the 16th meeting of the Contact Expert Group on Severe Accident Management (CEG-SAM) of the International Science and Technology Centre (ISTC) and of the Science & Technology Centre in the Ukraine (STCU).

He expressed his thanks to M.Veshchunov (IBRAE) who kindly offered to organize and host the 16th CEG-SAM meeting in Moscow.

**Topic #2:** Adoption of the agenda of the 16th CEG-SAM meeting

The planned presentation of B.Konorev (I&C SCC) on the **Status of the STCU project #4726 on “Safety-critical software independent verification and latent faults assessment based on diverse measurement of invariants”** (topic #25) will not be given. With these changes, the appended agenda (see Annex 1) was accepted.

**Topic #3:** Approval of the minutes of the 15th CEG-SAM meeting in Villigen, Switzerland, March 10-12, 2009

The secretary took into account the comments received on the draft minutes by the participants in the revised minutes. The revised minutes were then approved by the CEG-SAM members without any additional changes at the 16th CEG-SAM meeting in Moscow, September 8, 2009.

**Topic #4:** Discussion of the “Action List” of the 15th CEG-SAM meeting in Villigen

**Action 15/1**: L.Tocheny (ISTC) and M.Hugon (EC) will invite members of the SAC to the 16th CEG-SAM meeting in Moscow, September 2009, to discuss possible future research activities in the framework of the CEG-SAM. *Action was not executed because of sharp decrease of funding for projects in ISTC/STCU.*

**Action 15/2**: J.Stuckert (FZK) will interact with V.Nalivaev (LUCH) and A.Kisselev (IBRAE) to integrate their various reports on PARAMETER test results into the CEG-SAM webpage. *Action completed*.

**Action 15/3**: D.Bottomley (JRC-ITU), Ch.Journeau (CEA), M.Krause (AECL), G.Pretzsch (GRS) and W.Tromm (FZK) will prepare an advice on how the STCU project proposal #4758 on “Characterization of hidden fuel in the ChNPP” could be re-directed to obtain valuable results for code validations. The advice should be circulated to the CEG-SAM members before it will be sent to V.Krasnov (ISP NPP). *D. Bottomley and G. Pretzsch revised the proposal and send it to V. Krasnov. Up to today they have not yet received his comments*.

**Action 15/4**: S.Güntay (PSI), J.Stuckert (FZK) and K.Trambauer (GRS) will prepare an advice on the planned PARAMETER-SF5 and –SF6 test parameters (ISTC #3936) and send it to V.Nalivaev (LUCH) for further discussion at the 16th CEG-SAM meeting. *Action completed*.

**Pending actions**

**Action 14/4**: M.Hugon (EC) will supplement the CEG guidelines concerning the future extended scope of activities of the group to include also developments of numerical codes and experiments on safety (neutronics + thermal hydraulics). *(suspended until the results of the evaluations of the 3rd call of FP7 in July 2009).Action was not completed because no proposals were submitted in this area at the 3rd call of FP7.*

**Action 14/5:** M.Hugon (EC) will write an E-mail to J. Sanders (DG RTD – ISTC Secretariat) to be transmitted by him to the European members of ISTC/SAC and of the similar committee for STCU to ask them to re-consider the funding of ISTC project proposal #3702 (CHESS-2) at the next GB meeting as well as that of STCU project proposal #4207. Both proposals address the long-term behaviour of the corium lava after the Chernobyl accident. *STCU project # 4207was funded by Canada,* *but project proposal # 3702 was not supported by SAC and therefore not funded*. *This action is now suppressed because of sharp decrease of funding for projects in ISTC/STCU.*

**Action 14/7:** L.Tocheny (ISTC) should provide invitations and visa support for the foreign participants at the 16th CEG-SAM meeting in Moscow in September 2009 (this request was expressed by IBRAE to CEG-SAM after the meeting). *Action completed*.

**Topic #5**: Reports by the secretariats

M. Hugon reported on the present status of the CEG-SAM and its possible future evolution (see Topic #10).

S.Vorobiev, the Russian Deputy Director of ISTC, discussed the future role of the CEG in the research area of nuclear safety as a result of the dramatically decreased ISTC budget. The next ISTC GB meeting will be on December 10, 2009. The next STCU GB meeting is planned on November 17, 2009.

A.Gozal (ISTC) mentioned that partnership projects (co-funding by end-users) have to be considered in the future. If the CEG-SAM is interested in a project proposal which received the status #3 (accepted without funding) by the ISTC-GB it should send a request to ISTC to explain the importance of the project for the group and ask them to re-consider the project by the GB.

**Topic #6**: Preliminary discussion of updated and/or new ISTC/STCU project proposals

The new and updated ISTC/STCU project proposals will be presented and discussed under the topics #26 until #29.

No new facts were presented on the ISTC project proposal #3919 VERONIKA. The proposal was discussed at the last ISTC-GB meeting and was accepted without funding (status #3). ISTC/STCU projects with the status #3 will not be funded by the European Commission but can be funded by interested partners as a general rule.

Also the ISTC project proposal # 3936 PARAMETER-SF5 and –SF6 (Topic #28), in which the CEG-SAM has a strong interest, was considered at the last ISTC-GB meeting and was accepted without funding (status #3).

The STCU project proposal #4758 on “Natural and calculation-experimental research of processes of fuel melt interaction with construction materials for severe radiation accidents on nuclear power plants” has not yet been funded although it is assigned with the status #6; project underway.

The ISTC project proposal #1411 on “Experimental and numerical study of liquid metal boiling as simulation of accidents in a fast reactor core” was sent to the CEG-SAM members by L.Tocheny just before the meeting. It was assigned the status #3 by the GB about 10 years ago. The proposal was presented under topic # 29. The ISTC project proposal #3627 on “Grid usage technology development for safety analysis of power reactors” will not be presented and was therefore not considered by the group. In addition, the scope of this project is outside the topics of the CEG-SAM.

# Extended session

**Topic #7**: V.Strizhov (IBRAE) welcomed all the participants at the meeting and he stressed the importance of international co-operation.

**Topic #8**: Welcome of the Russian, Kazakh and Ukrainian colleagues; approval of the shortened minutes of the 15th CEG-SAM meeting in Villigen; adoption of the agenda of the 16th CEG-SAM meeting in Moscow.

M.Hugon opened the extended session of the meeting and welcomed the Russian, Kazakh and Ukrainian participants and expressed his thanks to M.Veshchunov (IBRAE) for organizing and hosting the 16th CEG-SAM meeting.

The shortened minutes of the 15th CEG-SAM meeting were distributed to the Russian, Kazakh and Ukrainian participants by the secretary. The obtained comments had been considered in the revised shortened minutes. This version of the minutes was accepted at the meeting without any additional changes.

The presentation of V.Protsak (topic #24) on the status of the STCU project #4207 on “Long-term prognosis of the behaviour of the fuel dust in the Chernobyl Shelter” will be presented by V.Krasnov (I&C SCC). The planned presentation of B.Konorev (I&C SCC ) on **the STCU project #4726 on “Safety-critical software independent verification and latent faults assessment based on diverse measurement of invariants” will not be given (topic #25)**. With these changes the appended agenda (see Annex 1) was accepted.

**Topic #9**: Status of the official ISTC CEG-SAM webpage

The ISTC CEG-SAM webpage is hosted by GRS (Garching, Germany) and is now fully operational (http://cegsam.grs.de). In the new structure of the webpage all documents (project proposals, advice notes, work plans, progress reports) are collected under the ISTC project number. There will be a unique user name and password for each user and different read/write permissions for the different users. The Russian, Kazakh and Ukrainian project managers will be exclusively responsible for updating the project documentation/deliverables and the upload of presentations from project progress meetings.

The CEG-SAM members will have full access to the agendas, list of participants and minutes (restricted and open sessions) and all other stored documents (presentations). There will be special access rights for non-European members for the project in which they participate.

**Topic #10**: Future of the CEG-SAM

M.Hugon gave a presentation on the status of the ISTC contact expert group CEG-SAM. It has been quite successful since its launching in April 2002. Up to now, 14 ISTC projects have been funded, 7 of them being completed and 7 others are still running. 2 STCU projects have been funded with one running and the other under negotiation. The interaction between the CEG-SAM and SARNET/SARNET2 is excellent. Results of SARNET2 activities are periodically presented to CEG-SAM members and ISTC/STCU proposals and project reports related to SAM are transmitted to the SARNET2 topical co-ordinators.

The current ISTC and STCU project proposals of potential interest for the CEG-SAM are: 1) STCU #4758, Hidden nuclear hazardous clusters of fuel in the Chernobyl NPP Unit 4; 2) STCU proposal #5243 on “**Interaction Studies of Improved VVER Structural Materials at Severe Accident Conditions**”; 3) ISTC #3936 Fuel assembly tests with B4C absorber material, PARAMETER-SF5 +SF6 experiments; 4) ISTC proposal #1411 on “Study of liquid metal boiling as simulation of accidents in FNR core” and 5) ISTC #3919, VERONIKA: “Study of fission products release and behaviour of VVER fuel with high burn-up under severe accident conditions”.

The proposed projects PARAMETER and VERONIKA, which are of great interest of the CEG-SAM, were considered at the last ISTC GB meeting and both proposals were assigned with status #3 (accepted without funding).

The ISTC/STCU funding from EC amounts to about 8M€ in 2009, but the basic annual costs of ISTC and STCU is about 6M€; therefore, the funding for proposed projects in 2009 is limited to about 2M€. The EC funding for ISTC/STCU for 2010 is not yet known.

M. Hugon presented briefly the results of the evaluation of the proposals submitted in response to the third call on nuclear fission and radiation protection in FP7. In particular, concerning the topics proposed by the Euratom - ROSATOM working group for which cooperation with Russia was welcome, proposals with Russian partners were accepted for funding for three of them: (i) ageing and lifetime management of RCS; (ii) RPV integrity assessment for long term operation; (iii) Lead Fast Reactor. These proposals will be funded even if the Russian partners cannot participate due to lack of funding from ROSATOM. Concerning the subjects for which cooperation with Russia was essential, three proposals were accepted for funding: (i) Education and training (ENEN-RU); (ii) Containment thermal-hydraulics of LWRs for severe accident management (ERCOSAM); (iii) Molten salt reactor (EVOL). These European proposals will be funded by Euratom, only if ROSATOM finances the parent Russian proposals. Both European and Russian projects will be coordinated by an overarching agreement.

*Note from the Secretariat:* The Commission is still waiting for the answer of ROSATOM to the letter of the Director of Energy (Euratom) of DG Research. This answer should give assurance that ROSATOM will fund the Russian projects.

Concerning the near future, if the ERCOSAM project is funded, it will be included in the CEG-SAM. The possibility of establishing a structured dialogue between Euratom and the Ukraine will be investigated. Ukrainian-Euratom projects could be funded as follows: Euratom will finance the European part and the Ukrainian part will be financed by Ukraine.

**Topic #11**: Update on SARNET2

B.Clément (IRSN) presented the SARNET2 (**S**evere **A**ccident **R**esearch **NET**work of excellence) update. SARNET2 started on April1, 2009; altogether 21 countries with 41 organizations are participating in the programme that will last 4 years. The total effort is about 10M€ per year with about 1.5M€ per year of EC funding. The main objectives of SARNET2 are to tackle the fragmentation that exists between the different R&D organisations, notably in defining common research programmes and developing computer tools; in particular the continuation of ASTEC assessment and its extension to cover BWRs and CANDU reactors.

B.Clement described briefly the work on Severe Accident Research Priorities within SARNET2. Six issues remain open with high priority, four issues with medium priority, and five issues remain open with low priority and could be closed after finalizing the related research activities. The 6 issues with **high priority** are research on 1) core coolability during reflood and debris cooling in lower head; 2) ex-vessel melt pool configuration during MCCI and ex-vessel corium coolability by top flooding; 3) corium melt relocation into water and ex-vessel fuel coolant interaction; 4) hydrogen mixing and combustion in the containment; flame acceleration; 5) the impact of oxidising conditions on source term; 6) iodine chemistry in the RCS and in the containment. The tasks of SARNET2 will be executed by 8 work-packages on management, spreading of excellence (courses, conferences), information systems, ASTEC, corium and debris coolability, MCCI, steam explosion and hydrogen combustion in containment and oxidising impact on source term.

Up to now the interaction between CEG-SAM and SARNET2 works well and the SARNET2 recommendations were considered in the final work programmes of the various ISTC/STCU project proposals. The results of ISTC/STCU projects are used by foreign collaborators in the framework of SARNET2. The interaction between SARNET2 and CEG-SAM brings mutual benefits and further assures a critical mass of expertise for ISTC/STCU proposals addressing specific issues in the SAM area. The objective of the interaction is the resolution of still-pending questions that are important for reactor safety, and the knowledge transfer for safety application.

The next main milestones of SARNET2 are joint workshops, conferences and education courses. The 4th ERMSAR conference will take place in Bologna, May 10 to 11, 2010. A joint OECD/CSNI and WP5 workshop on in-vessel coolability will take place in Paris on October 12 to 14, 2009. The 1st GB meeting should be held around March 2010.

**On-going project presentations**

**Topic #12:** Status of the ISTC project #3690 on the “Fuel assembly behaviour under severe accident top quenching conditions in the PARAMETER-SF test series (PARAMETER-SF3 and PARAMETER-SF4 experiments)

V.Nalivaev (FSUE SRI SIA, “LUCH”) presented the current status of the project PARAMETER that includes the conduct of VVER-1000 bundle experiments with UO2 pellets and Zr+1%Nb cladding tubes under severe reactor accident conditions (18 heated rods and 1 unheated rod). The PARAMETER-SF4 experiment was conducted on July 21, 2009, in an air environment with bottom quenching under the following test conditions. Coolant flow rates: argon 2g/s (670K), steam 3.5g/s (770K) and air 0.5g/s. The pre-oxidation of the bundle was carried out at cladding temperatures of about 1470K for about 6000s. Then the bundle power was decreased to reduce the temperature to about 1200K and switch the flow from steam to air before it was heated up to a maximum bundle temperature of about 2000K. At this temperature bottom flooding of the bundle with water (80 g/s) was initiated. The bundle cool-down took approximately 1000s. The test parameters for the bundle experiments (heat-up rate, steam flow rate, extent of pre-oxidation of the cladding, maximum cladding temperature before quenching, flooding rates) were fixed on the basis of different code predictions (see topic #13).

The measured cladding temperatures of the bundle were presented as function of time for different bundle elevations during the pre-oxidation and transient heat-up and quench stages. The total mass of hydrogen generated during the test was 110g maximum. The amount of hydrogen measured during the pre-oxidation of the bundle has not exceeded 21g. Post-test destructive examinations of the fuel bundle will be performed to determine the extent of cladding and shroud oxidation and will be compared with code predictions.

**Topic #13:** ISTC project #3690. Results of PARAMETER-SF3/-SF4 pre- and post-test numerical modelling

D.Tomashchik (IBRAE-RAS) presented the results of PARAMETER-SF3/-SF4 pre- and post-test calculations performed with different SA code systems: SOCRAT, ICARE/CATHARE, RELAP/SCDAPSIM/MOD3.2, PARAM-TG, MAAP-4, SCDAP/RELAP/IRS and ATHLET-CD, respectively. In a PARAMETER project progress meeting in Moscow in July 2009 the test parameters on pre-oxidation, cool-down, air ingress and bottom quenching were fixed. The jointly agreed and applied test stages are described in detail in topic #12. The test PARAMETER-SF4 should be considered as a counterpart test to the bundle test QUENCH-10 conducted in Germany.

D.Tomashchik presented and discussed the results of the calculations with various code systems for the different test sequences of the bundle test PARAMETER-SF4.

The PARAMETER-SF3 post- and pre-test calculations have been compared with the obtained experimental data. Beside the temperature evolution of the cladding and shroud also the oxide scale thicknesses at different bundle elevations as well as the generated hydrogen were determined. The comparison reveals that the applied experimental electric power at the pre-oxidation and the transient phase was higher than calculated. Post-test calculations were performed on the basis of the exact PARAMETER-SF3 experimental data of power history, mass flow rates, and inlet temperatures. In the course of the PARAMETER-SF3 post-test calculations, the heat loss in the external resistances (leads and electrodes) and the radial heat loss through the shroud, which were not exactly known, were improved.

All codes reproduce reasonably well the temperature evolution of the bundle. The calculated maximum temperatures before the onset of flooding correspond to the experimentally-measured ones (1870 K). At the flooding stage all codes predict practically no hydrogen release. Most code systems estimate the total amount of hydrogen well; the best coincidence between the experimentally-determined hydrogen mass (34 g) and calculated mass was achieved in calculations by the ICARE code system (about 33 g). The results of RELAP/SCDAPSIM calculations are always lower or different to the other code calculations.

**Topic #14:** ISTC project #3690. Post-test examination of the PARAMETER-SF fuel assemblies

T.Yudina (IBRAE-RAS) presented the status of the PARAMETER-SF2 and –SF3 destructive post-test investigations. Five bundle cross sections of the test bundle PARAMETER-SF2 were examined in detail. There was pronounced oxidation of the Zr+1%Nb cladding at bundle elevations between 1000 and 1300mm. Beside the formation of a compact ZrO2 layer on the outer cladding surfaces, a localized spalling of thin ZrO2 multi-layers took place. The cladding of the bundle elevations between 500 and 1300mm reveals pronounced breakaway oxidation. Quantitative data on the oxide layer thicknesses were given. The crack surfaces in the metallic part of the cladding (through-wall cracks) were not oxidized. The oxidation of the inner cladding surface is weak. Cladding fragmentation is not pronounced. No UO2 fuel relocation took place. The pickup of hydrogen by the shroud was measured at different elevations. The maximum hydrogen concentration was about 23 at% at 900mm elevation.

In addition the final results of metallographic examinations of the test bundle PARAMETER-SF3 at different cross sections were described and discussed in detail. The bundle showed pronounced breakaway oxidation of the cladding, shroud, and peripheral rods, especially at the higher and hotter bundle elevations. The oxide layer thickness on the outer cladding surface varied between about 250µm at the bundle elevation of 800mm and about 550µm at 1300mm. The maximum shroud oxidation was about 400µm based on residual metal thickness at the heights of 1050 to 1350mm. This zone corresponds to the bundle's hottest zone (1300mm) according to the thermocouple readings The circumferential cladding oxide layer thickness was inhomogeneous. Through-wall cracks in the cladding were not oxidized. The oxidation of the inner cladding tube surfaces was weak. The Ta heaters and Mo electrodes were partially oxidized in the upper bundle elevations. .

**Topic #15**: Status of PARAMETER-SF4 planning analyses by EU partners

S.Guentay (PSI) presented the joint opinion of the EU partners on the key test objectives and proposed test parameters of the planned experiment PARAMETER SF-4. The test objectives are: 1) Achieve air oxidation, but limited to enable a significant period of oxygen starvation. 2) Achieve reflood successfully without significant excursion and without melting/degradation. 3) Complete ZrO2/ZrN formation would be interesting but is less important than achieving oxygen starvation.

Following an action decided at the 13th CEG-SAM meeting held in Budapest, March 2008, PSI is coordinating the pre-test analytical support for PARAMETER-SF4. A task group was set up among collaborators and first scoping calculations were presented at the PARAMETER meeting held at Podolsk, in July 2008. A meeting was held at FZK on September 1, 2008, to clarify the most important test objectives, to identify a target transient and to define a schedule of calculations. Among the goals are to achieve a transient analogous to QUENCH-10, including a period of complete oxygen consumption (in order to investigate nitriding), and to avoid an oxidation excursion during reflood in order, as far as possible, to preserve the bundle in its post-air-ingress state. The outcome of the meeting was reported at the 14th CEG-SAM meeting in Kiev, shortly afterwards in September 2008. Due to difficulty of the test objectives and uncertainties in the air oxidation the task was completed by July 17, 2009, with the incorporation of pre-test calculations using ICARE/CATHARE code by the project. The test was successfully conducted on July 21, 2009, with clear indications that the target conditions were met.

The coordination has been supported by the EU in the frame of the SARNET programme under work package WP14.1. It was stressed that the contribution of European collaborators paved the way to the success of these PARAMETER projects. It is expected that EU support will continue within SARNET2.

**Topic #16**: Progress report on the ISTC project #3592 "Corium Melt Interaction with Reactor Vessel Steel” (METCOR-P)

S.Bechta (RIT-NITI) described the objectives of METCOR-P project: Qualification and quantification of physico-chemical phenomena of corium melt interactions with reactor vessel steel with particular interest to interaction characteristics i) at vertically-positioned interfaces, ii) peculiarities of interaction with European vessel steel, and iii) corium melt oxidation effects.

S.Bechta described the objectives and results of the conducted test MCP-4. The test MCP-4 was intended to determine the corrosion rate of European reactor vessel steel (20MnMoNi5-5) due to interactions with molten corium under oxidizing conditions and compare the results with the corrosion rate of Russian vessel steel (15Kh2NMFA).

During the first stage of the test a corium mixture of 71 mass% UO2 and 29 % ZrO2 was used. Three almost steady state temperature regimes were realized with temperatures at the corium/steel interface between 1000 and 1200°C. At higher temperatures Fe was added to the UO2/ZrO2 melt to form a molten pool of (UO2+x-ZrO2-FeOy). The completion of the corium oxidation was determined by measurements of the oxygen concentration in the air at the exit of the test section. The corium composition (UO2+x-ZrO2-FeOy) was used in the second stage of the test when three almost steady state temperature regimes between 900 and 1250°C at the interaction interface were established.

Preliminary results of the test show that the corrosion rate of the European vessel steel is comparable with that of the Russian vessel steel. Similar to the VVER steel, an intensification of the European steel corrosion occurs at the interface vessel steel/molten corium if the interface temperature exceeds some limiting value. Four more tests are planned according to the test matrix of the METCOR-P project.

A list of published and currently prepared papers was presented.

**Topic #17**: Progress report on the ISTC project #3813 “Phase relations in corium systems” (PRECOS)”

S.Bechta (RIT-NITI) described the objectives of the project **PRECOS. The** subject of the project is the experimental investigation of phase diagrams of oxidic and metallic-oxidic corium systems that form as the result of core meltdown and interactions of melt with construction and structural materials of the reactor core, concrete shaft, and core catcher.

The following systems will be studied in PRECOS: 1) Binary and ternary oxidic systems (CaO-UO2, CaO-FeO, SiO2-UO2, UO2-FeO-SiO2, UO2-FeO-CaO, ZrO2-FeO-SiO2, and ZrO2-FeO-CaO) that contain components of concrete and sacrificial materials, i.e., of importance for modeling the interaction of corium with materials of the concrete shaft and core catcher. The SiO2–containing systems should be specially mentioned, as their high viscosity and low conductivity make their experimental investigation problematic. These systems are very important for modeling the ex-vessel corium behavior. 2) Metallic-oxidic systems U-Zr-Fe-O with different concentrations of components, especially in the miscibility gap. 3) Multi-component mixtures representing prototypic ex-vessel corium.

Results of experiments in the SiO2-UO2 system, to define the monotectic temperature and the shape of the miscibility gap, and in the systems U-Zr-O, CaO-UO2 and ZrO2-FeOy were presented and described in detail. In the SiO2-UO2 system a large amount of new experimental data has enabled the improvement of the phase diagram. In the system CaO-UO2 the liquidus temperatures at high CaO content and the melting point of CaO have been determined (previously there had been a substantial difference between theoretical and measured values). Test results on the determination of the solidus temperature in the system ZrO2-FeOy and the composition of the solid solution ZrO2(FeOy) at the eutectic temperature were presented and discussed. The eutectic temperature in the system ZrO2-FeOy was defined more exactly.

**Topic #18a:** Progress report on the ISTC project #3876 on “Thermo-hydraulics of U-Zr-O molten pool under oxidising conditions in multi-scale approach (THOMAS)”; part #1

M.Veshchunov (IBRAE-RAS) described the objectives and work plan of the project THOMAS and its current status. Non-destructive and destructive post-test examinations of bundles in various tests showed the formation of molten pools of different scales at various stages of core degradation. Small local pools were observed at different elevations in bundles in the early stage of core degradation in CORA and QUENCH tests. Results of the PHEBUS -FP tests confirmed that a significant part of the fuel bundle was liquefied and that the amount of fuel damage was close to TMI-2 with an extended molten pool located in a central zone of the bundle underneath a cavity. In the late stage of a severe accident, the formed melt can relocate into the lower head of the reactor pressure vessel and form a large molten pool interacting with cooled walls.

M.Veshchunov presented results of the Task 1 of the project “Development and improvement of the physico-chemical model for the U-Zr-O melt oxidation on the basis of new crucible tests”. The main stages of molten U-Zr-O corium interactions with vessel steel (VS) walls are analysed. During the initial transient stage a rapid ablation of VS takes place under formation of a solid or mushy (depending on oxygen content in the melt) crust controlled by rapid heat exchange processes accompanied with mixing of the melt. This stage can be generally described by thermo-hydraulic codes (i.e. to be realized in the CONV code).

During the subsequent steady state stage the heat and mass exchange processes between melt, crust and walls should be considered self-consistently, taking into account steep temperature gradients and oxidizing conditions in the melt. During this stage, the following physico-chemical processes simultaneously take place: conversion of the crust from a mushy to solid one; accompanied with a growth of the formed crust, and corrosion (oxidation) of the SS walls, which are strictly controlled by oxygen transport through the multilayered structure. The growth of the solid crust due to oxygen transport through the melt to cold walls is described by the SVECHA Melt Oxidation (MO) model, developed within the previous ISTC Project #2936, which will be refined on the basis of new FZK crucible tests within the current project.

The corrosion of VS walls is analyzed using the experimental data from the ISTC Project METCOR. The available SVECHA model for steel oxidation in steam and which is based on the parabolic correlation derived from the KI tests for 06Х18Н10Т steel is modified for 15 Kh2NMFA vessel steel (using METCOR data) and supplied with the “oxygen starvation” regime consideration, in which VS oxidation kinetics is controlled by external oxygen flux. The starvation regime is valid during relatively long period of corrosion when the corrosion layer is relatively thin in comparison with the crust thickness, thus, transport of Fe and/or oxygen ions through this layer is a relatively quick process and its growth is controlled by the oxygen flux from the (solid or mushy) crust.

The VS corrosion model is numerically realized and implemented in the melt oxidation (MO) model. The new model was tested and then applied to typical temperature scenarios of tests carried out in the on-going ISTC project METCOR-P (#3592). The model allows interpretation of the main test observations and qualitatively describes VS corrosion kinetics observed in low- and high-temperature regimes. The interactions become especially complicated in high temperature tests with eutectic formation at the interface between corrosion (FeO) and crust (U,Zr)O2 layers. This results in accelerated VS corrosion kinetics described by the new model using “flowering” mechanism. After additional refinement and validation, it is foreseen to start modification of the new physico-chemical interactions model and its preparation for implementation in the thermal-hydraulic code CONV.

**Topic #18b:** Progress report on the ISTC project #3876 on “Thermo-hydraulics of U-Zr-O molten pool under oxidising conditions in multi-scale approach (THOMAS)”; part #2

V.Chudanov (IBRAE-RAS) presented results of Task 2 of the project “Development and Improvement of the unified thermal-hydraulic technique (CONV Code) for simulation of multiphase processes in complex domains of convectively stirred melts”.

The numerical experiments at the choice of optimum turbulence model (algebraic type) were presented. The following models were considered: 1) approximated turbulence model, 2) algebraic turbulence model (Bolduin-Lomax) and 3) quasi DNS approach. In the considered case for a convection of a heat-generating fluid in the interesting range of Rayleigh numbers the approximating turbulence model was proposed and calibrated. The choice of algebraic models is stipulated by conceptual simplicity. As the algebraic models are so convenient, it is necessary to abstain from their use only, if the alternative, excluding their use is possible. However always it is necessary to remember a problem of incompleteness. The algebraic models will well work only for flows, for which they have been adjusted in details. Extrapolation outside the established database used for calibration of the algebraic model, is not recommended.

The results of the modernization of the CONV code and examples of its validation were presented on such tests as: convection in a cavity with the walls with different temperatures and convection of a heat-generating fluid, 3D convection in a lid-driven cavity flow, backward-facing step flow and full turbulent flow of water in a round pipe. The validation of the modified software on the available tests is successful and demonstrates a good agreement of numerical predictions with the experimental results.

**Topic #19**: Short overview on the main research activities at the “IBRAE RAS”; Visit of the laboratory of “Scientific and technical support of emergency response”

V.Strizhov (IBRAE RAS) described briefly the code development activities in the area of nuclear safety at IBRAE as: 1) safety codes for water-cooled reactors, 2) safety codes for liquid metal reactors, 3) advanced multi-physics three dimensional codes and 4) containment codes (MELCOR modernization project) .

The SOCRAT system of codes is built using the state-of-the art models for best estimate simulation of key severe accident phenomena. The code is extensively used for assessments of accident progression scenarios at NPPs with VVERs. After completion the code will allow modelling of accident phenomena from initiating events to radiological consequences. The other code development activities were presented and typical examples of application were shown. In particular, a 10-year programme has been launched on liquid metal fast reactors, including the development of safety codes.

The task of the visited laboratory is the assessment and prognosis of emergency facility conditions, recommendations for bringing the facility to a safe condition, assessment of radiological consequences and prognosis of radiation exposure and recommendations on radiation protection actions for environment and population.

**Topic #20:** Status of the ISTC project # K-1265 “Study of the processes of corium-melt retention in the reactor pressure vessel” (INVECOR)

V.Zhdanov (IAE NNC RK) described briefly the results of the performed INVECOR experiments. The objective of the in-vessel corium retention experiments (INVECOR), i.e. the improvement of the safety assessment of LWR corium in-vessel retention (IVR) and the modelling of the thermal and physico-chemical processes of the prototypical corium pool and its retention in the water-cooled RPV lower head.

The executed tasks were: 1) Fabrication of the graphite components for the electric melting furnace for the large-scale tests.

2) Two large scale tests have been performed in "Lava-B" facility using 60kg of prototypic corium that corresponds to C-32 corium; the mode of heat-up of the corium until it is molten has been specified during these tests.

3) Conduct of the first integral test INVECOR-1 using 60kg of prototypic corium corresponding to C-32 corium. In addition about 10kg of once molten corium has been placed into the RPV model before the test was started. The initial loading (60kg of corium components) has been heated-up and melted in the electric melting furnace up to a temperature of about 2500°C. The obtained corium melt was discharged into test section of the RPV model with a device for decay heat simulation. The total power of 5 plasmatrons was about 65kW during 1 hour. The maximum measured temperature of the RPV model wall was higher than 800°C. Post-test examinations of the experimental test section and the evaluation of the measured data are under way.

4) Recommendations for the test conditions of INVECOR-2 have been developed. It is planned to place the stainless steel sheet on the RPV model inner surface to simulate the VVER RPV design. In addition, the thickness of the thermal insulation of the bottom part of the RPV model will be increased to obtain a uniform heating of the RPV wall (in a later meeting of Ch. Journeau & D. Bottomley with Dr. Zhdanov it was also suggested that the pre-heating of the RPV should be about 800°C and that there is no outer water-cooling to help obtain creep conditions for the RPV). The preparations of the RPV test section and of the electric melt furnace are under way. The planned date for the test conduct is October 15, 2009.

The results of the performed INVECOR tests will be placed into CEG-SAM webpage as soon as they are ready. The conditions of the test INVECOR-3 were presented for further discussion with the foreign collaborators of the project.

**Topic #21:** Status of the ISTC project #3831 on “Development and experiments at large-scale installation for heating and retention of corium”

V.Kondrashenko (VNIIEF) described the main goal of the stage I of the ISTC project #3831 to examine experimentally the interaction of molten corium with concrete. It is planned to develop a medium-scale installation in order to heat-up corium along with the development of a diagnostic and measuring system. It will be a good solution to perform a medium-scale experiment at the first stage to test the technology in order to conduct large-scale experiments at the second stage.

The whole project consists of 3 tasks. Task 1: Development of technologies for the pyrotechnic production of briquettes for initiating the heating process and dumping them later into the corium. One cylindrical PTC (Prototypic Corium) briquette was produced: d=50mm, h=20mm, m=135g, ρ=3,44g/cm3. On the basis of preliminary experiments it was decided to ignite PTC with the help of an electric igniter and to subsequently sustain the process by means of three gas burners (that are also used for additional heating of corium) using a propane-oxygen mixture. Tests of remote-controlled dumping of PTC briquettes into corium were initiated.

Task 2: Development of the measuring equipment complex for the diagnosis of the corium temperatures and thermal fields in the concrete and to develop and install a temperature measuring system for the melt temperature by means of pyrometry. To measure the corium surface thermal radiation a four-channel pyrometer was developed. A measuring system of thermocouples was developed and calibrated to measure the melt temperature and heat flows in the concrete

Task 3: The development of a medium scale installation for corium heating with the following characteristics: corium volume ~15-18l corium mass ~100-120kg, corium temperature ~2500-3000°C, heat fluxes towards walls and a bottom of a tank ~100 kw/m2, melt retention time 10-12min. A concrete tank was prepared that contains 8 built-in thermocouples for the small-scale experiment with ~3kg of PTC. The tank dimensions are: inner diameter =150mm, full height =260mm, bottom thickness =100mm, side walls thickness =100mm.

The various tasks have been fulfilled and approved. The technology of PTC ignition by means of electric igniter and a system of 3 gas burners to heat the corium as well as the different measuring devices were successfully tested.

The CEG-SAM expressed its opinion that the planned large-scale experiments are only of interest if it will be performed with UO2-containing “corium”. The opinion of the CEG-SAM is that there have been enough other MCCI experiments performed with simulated corium materials. Simulant materials are acceptable for the technological test at medium-scale but an assurance must be given that uranium-containing melts will be used for the large-scale experiment in the second stage.

V.Kondrashenko pointed out that meeting on the MCCI project (ISTC #3831) is planned with some CEG-SAM members at the ISTC Headquarter for the 10th of September, 2009. At this meeting more time will be available to discuss the status and future activities of the project in detail with the collaborators (see minutes of this meeting prepared by Ch.Journeau; Annex # 4). A project progress meeting on MCCI will take place in Sarov on November 24 to 25, 2009 (topic #22).

**Topic #22:** Discussion on future visit of collaborators and CEG-SAM members to Sarov

Ch.Journeau (CEA) described the importance of the planned MCCI tests by VNIIEF in Sarov. The pre-tests will be performed with Zr instead of U to prove the continuous heat generation and the suitability of the developed measurement technology. However, the objective will be a large-scale long-term MCCI test with prototypic corium.

Details of the planned project progress meeting in Sarov, scheduled for November 29, 2009, were discussed. Altogether 10 Collaborators and CEG-SAM members will participate at the meeting in Sarov. The assistance of ISTC for practical and administrative preparation of this meeting by VNIIEF (visas, closed city permits, lodging, domestic transportation) has been requested.

**Topic #23:** Status of the ISTC project #3635 on “Scale experimental investigation of the thermal and structural integrity of the VVER pressure vessel Lower Head in severe accidents”

V.Loktionov (MPEI) presented the current status of the project. The overall objective of this project is the experimental and numerical study of VVER-440 lower head (LH) reactor vessel models under thermal and overpressure loadings corresponding to realistic SA scenarios. The different tasks are the manufacturing of the VVER LH reactor vessel scale models (1:5), the conduct of the scale experiments with VVER vessel models at high temperatures as well as separate-effect tests on the creep behaviour of the VVER vessel steel and numerical pre- and post-test analyses of the scale experiments.

The expected results will be experimental data on the creep behaviour, heat-up and failure of the VVER-440 vessel material. The data will be used for verification of thermo-mechanical codes that are used in safety assessment in SA management strategy for NPPs.

For the calculations and analytical analysis the power Unit 1 of Kola NPP (VVER-440/V-230) has been chosen as reference reactor plant. The goal of the calculations was to estimate the decay heat power level in the lower plenum. Parametric calculations were carried out using the codes SOKRAT and NARAL assuming different masses of debris relocating into the lower plenum after core disruption. Depending on the relocated mass (7-40t that corresponds to 1.2-12MW decay heat) the time of vessel failure varied between 4 and 25 h. At about 1MW decay heat the melt may be kept in the vessel without effective cooling.

In this context, the project efforts are focused on the following problems: 1) Designing and construction of the test facility for test examinations of the VVER vessel scale models. The experimental facility to be built includes: working space, scale model and its heater, control and experimental information gathering system (DAS), support systems (gas, water systems, video-monitoring devices etc.).

2) The manufacturing of the VVER LH reactor vessel scale models. The material and thermal treatment of the vessel steel have to correspond to the same conditions as for a regular VVER vessel.

3) The execution of the material creep test experiments with samples from the VVER vessel steel in the time range of 2-50 hours and a temperature range from 600 - 1200°C to obtain creep data for refinement of the constitutive creep model and extend the data on the mechanical characteristics of this steel.

4) The conduct of scale experiments with VVER vessel models on the high-temperature heat-up and creep deformation of the vessel.

5) The mathematical treatment and analysis of scale experiments, carrying out the numerical pre- and post-test structural analyses of scale experiments with vessel models by means of the domestic code ATM-VVR and by commercial codes MSC-Marc, MELCOR, RELAP/SCDAP for validation of the physical models implemented in these codes.

The development and manufacturing of the experimental test facility and supporting systems for the VVER scale vessel models testing was described. The geometrical scale of the vessel model is 1:5 with an inner diameter of 700mm and a wall thickness of 20-30mm. The vessel model will be of the VVER vessel steel 15Kh2NMFA. For the heating of the experimental vessel models it is planned to use 2 power transformers with a total capacity up to 200kW. Creep experiments with the vessel steel were carried out in the temperature range from 750 to 1050°C up to 50h at constant loads in argon and air.

M.Hugon proposed that a project progress meeting should be organized to discuss the manifold analytical and experimental results in detail with the foreign collaborators.

**Topic #24:** Status of the STCU project #4207 “Long-term prognosis of the behaviour of the fuel dust in the Chernobyl Shelter”

V.Krasnov (ISP NPP) presented the project progress on behalf of V.Protsak (ISP NPP) who was not able to attend the meeting. The Chernobyl shelter of the RBMK-1000 Chernobyl NPP unit 4 is a source of radioactive particles that formed during the accident (now present inside the construction in the form of dust) and in the subsequent period due to physical-chemical destruction of the fuel containing material (FCM). In view of the planned transformation of the “Shelter” into an ecologically safe system, the presence of the fuel dust in the shelter (about 30000kg) will become a serious problem. In spite of the numerous data on the characteristics, composition and localization of the fuel dust in the shelter, the mechanisms of its formation and, especially, the prognosis of its further physical/chemical transformation are still not clear.

V.Krasnov described the physical-chemical characteristics of the Chernobyl fuel particles and mechanisms of their formation. The project studies will be focused on the fuel particles and main types of the fuel-containing materials (FCM) in the shelter, as well as on the mechanisms governing their destruction. Experimental data show that the FCM destruction in the present time occurs due to internal and external influences. It results in the FCM transformation into the highly-mobile and highly-radioactive dust.

Therefore, it is very important to carry out experimental and theoretical studies within the framework of the project, which will enable the formulation of a model of the long-term behaviour (50-100 years) of the fuel dust under the shelter conditions. The model must describe both the transformation of the existing fuel particles and the processes of their formation from the main types of the FCM.

During the reported period the criteria of modernization of the existing database on “Hot particles” (HP) have been determined aimed in its extension (updating with the new information) and improving the interface for formulation of various correlations between the HP parameters which will be used for modeling the HP behaviour under shelter conditions. According to the most optimistic prognoses, the radiation destruction of LFCM will be possible only in millions of years, while the pessimistic assessments predict such a dangerous scenario in the near future. Analysis of the literature data shows the urgency and complexity of the investigations planned within the framework of the project.

For the identification of the main sources of radioactive aerosol (RA) in the shelter the experimental works have begun by sampling aerosols and water. The airborne concentrations and dispersal composition of RA which passed through the ventilation pipe VT-2 from the central hall of Shelter to the atmosphere has been studied. The samples were taken in the room 2016/2 through the hatch in the “Bypass” pipe and from the main water agglomerations at a low level of the Shelter. Gamma- and alpha-spectrometric analyzes of the collected samples are in progress.

**Topic #25: Status of the STCU project #4726 on “Safety-critical software independent verification and latent faults assessment based on diverse measurement of invariants”**

The presentation of B.Konorev (I&C SCC) was not given since he was not able to attend the meeting.

**Updated and new project proposals**

**Topic #26:** Status of the STCU project #4758 on “Natural and calculation-experimental research of processes of fuel melt interaction with construction materials for severe radiation accidents on nuclear power plants”

V.Krasnov (ISP NPP) presented the status of the STCU project although its financing is not yet settled. The expected new results of the project will be: visual information and data obtained by drilling new boreholes; analytical results of sampled fuel-containing materials (FCM); instrumental measured data; mechanisms of FCM cluster production with high - content of uranium.

On the basis of the above data, as well as on the basis of neutron and heat estimates, new instrumental measurement data and results of physico-chemical properties of samples taken from the cluster area, the following results will be obtained: 1) the structure, geometry and FCM physico-chemical properties in two critical mass risk areas in the south-west quadrant of room 305/2 of the ChNPP Unit 4 (object «Shelter»); 2) neutron physical processes occurring in clusters under impact of external factors.

The investigation of a neutron anomaly in June, 1990 has shown that there occurred a critical incident. The interpretation of the incident on the basis of a congestion model has allowed estimating the geometrical and mass parameters of the material accumulation. In this zone are about 40t of FСМ with a concentration of fuel with more than 50 weight% of uranium. The aggregation of FСМ, which has an unknown structure, constantly in water, may be subcritical with Kef>0,98. The decrease of the water volumes in a FCM cluster connected with a temperature growth can result in a self-sustained chain fission reaction. In the absence of detailed information on the structure, the physical, chemical and neutron-physical characteristics of the cluster, the definition of preventive measures to suppress the criticality is obviously not possible. In the course of the investigations nuclearly - hazardous clusters of fuel-containing materials in destroyed ChNPP Unit 4 should be reconsidered and assessed. Moreover, the results of this assessment could provide valuable insight to the phenomenology of molten core concrete Interaction.

**Topic #27:** STCU project proposal on “Interaction studies of WWER materials used in improved structural core components during severe accidents followed by high-temperature melt formation”

V.Kornyeyeva (NFC KIPT) presented the USTC project proposal. Measures must be developed to manage beyond design-basis accidents which result in severe damage of core components, melt formation and its variation with time. Of special interest is to know the behaviour of the fuel and absorber elements during a severe accident; the processes and kinetics of the material interactions of all core components with each other and with the environment under melt formation conditions. The determination of melt parameters such as viscosity, fluidity and chemical activity during the interaction with other solid state materials is also important. It has been indicated that KIPT had previously determined the thermo-physical properties of prototypes of Chernobyl corium (FCM).

The project is designed to obtain data on interaction parameters of materials in WWER improved core structural components; to obtain data on melt formation of fuel and neutron absorbers with the structural materials; to identify the phase compositions of the resulting melts in the solid state; to determine physical parameters of viscosity and fluidity of the melts of WWER core components.

The project intends to upgrade and prepare technological equipment and devices for the investigations; to develop designs and technological procedures to manufacture fuel element and absorber samples for the investigations; to develop procedures for experiments and investigations of the core material structures and compositions before and after their interaction (in the solid state and after melting); to obtain melts of standard WWER fuel and absorber element materials, namely, a combination of UO2-Zr1%Nb alloy (E110), stainless steels (EI 847, 630), boron carbide; to study the effect of fuel and absorber element designs on the interaction of material combinations as UO2–Zr and stainless steel–B4C; and to obtain temperature parameters for the beginning of melt formation versus the material state; investigation of melt formation processes of materials such as Zr+B4C, Zr + dysprosium-titanate, and (Zr+B4C+Hf) and interaction of these components with the melt of UO2+Zr fuel materials; to study phase composition of the resulting melts; to evaluate melt viscosity and fluidity depending on phase composition.

In the meantime the STCU project proposal has been officially registered under the title **"Interaction Studies of Improved VVER Structural Materials at Severe Accident Conditions" (STCU #5243).**

**Topic #28**: ISTC project proposal #3936 on “Study of fuel assemblies with boron carbide absorber rods under severe accident quenching conditions in the PARAMETER-SF test series (PARAMETER-SF5 and PARAMETER-SF6 experiments)

V.Nalivaev (LUCH) presented the objectives of the project proposal. Two fuel assemblies with 18 heated fuel rods and 1 central B4C absorber rod will be tested under SA conditions with quenching from the top. The proposed test conditions are: coolant flow rates (argon/steam) 5/3.5g/s; heating rate of the bundle 0.2-0.3К/s; temperature of pre-oxidation about 1470К; time of pre-oxidation 4000s. The maximal temperature of claddings should be for PARAMETER-SF5 about 1520К and for PARAMETER-SF6 about 1720К, respectively. Quenching from the top should be conducted with a water flow rate of about 40g/s.

The following information will be obtained within the framework of the project: 1) the physico-chemical behaviour of model fuel assemblies (FA) with boron carbide absorber rods (AR) under the initial stage of a severe reactor accident with top flooding. 2) The degree of cladding oxidation and of melting of the cladding, guide tubes and AR materials will be studied depending on temperature. 3) Chemical composition and structure of the solidified and relocated melts be obtained. 4) The database for the verification of severe accident codes will be broadened.

The obtained results can be used for the improvement of SA computer codes used (SOCRAT/B1, ATHLET, ICARE-CATHARE, etc.) and for justification of critical limits of NPP design and operation.

The ISTC project received the status “3” (accepted without funding) by the ISTC GB. M.Hugon mentioned that “LUCH” should also contribute financially to the project. V.Nalivaev explained that this will be the case.

 **Topic #29**: ISTC project proposal #1411 on “Experimental and numerical study of liquid metal boiling as simulation of accidents in fast reactor core”

A.Sorokin (SSC RT IPPE) described briefly the problems of accidents in a sodium-cooled fast reactor. An analysis of the safety of fast rectors under severe accident conditions with actuating the emergency protection and switching-off the circulation pumps has shown that, among others, one should solve the problem of fuel assemblies cooling under the regimes of sodium boiling. In this case, the core is heated-up at very low flow rates of the coolant in the circuit circulation.

The purpose of the investigations will be to study the physics and characteristics of the hydraulic and thermal processes under liquid-metal boiling in a system of parallel assemblies in the natural circulation circuit. Theoretical models and computer codes for estimating the stability of operation of water-cooled facilities must be checked and modified to be applied to the case of liquid-metal low-velocity natural circulation.

Systematic investigations of eutectic alloy boiling of sodium-potassium under natural circulation conditions performed in the SSC RF IPPE in the 90's resulted in a qualitative picture of the process and quantitative description of different phases of development of the two-phase liquid metal flow in a single fuel-pin assembly in a natural-circulation loop, i.e., the stable bubble flow, the unstable slug flow, which goes-over into the stable annular-disperse flow, and the heat transfer crisis with dry-out of the heat transfer surface.

The experimental facility for studying the liquid-metal boiling in a system of parallel assemblies is mounted in the sodium-potassium loop of the AR-1 installation in SSC RF-IPPE. The facility consists of two natural circulation loops; each containing an electrically heated pin-bundle simulator. Two assemblies with seven fuel elements are integrated in every circulation circuit. The tanks located above the assemblies are also connected to each other. Each assembly (loop) can operate independently through its own circulation circuit.

The experimental results of the investigations of the eutectic sodium-potassium alloy boiling in a system of two parallel channels simulating those of fast reactors are: 1) At a heat flux of approximately 130 kW/m2, the bubble flow regime changes over to the developed slug flow with strong oscillations of the coolant flow rate and the other parameters. 2) The onset of the oscillating process during coolant boiling in one of the assemblies arranged in parallel provides antiphase oscillations in the second assembly. These oscillation processes in different loops proceed in the antiphase mode. 3) Hydrodynamic interaction between the loops is the cause of a significant growth in the flow rate amplitude and of a possible “lock” of the flow rate or a flow reversal in the loops. It may also result in an increase in the temperatures of the coolant and the claddings and in the incipient heat transfer crisis. 4) The difference in the heat fluxes on the surfaces of heat-generating pins in parallel assemblies provides the enhancement of the “resonance” of the oscillating process. 5) Heat transfer coefficients under liquid-metal boiling in a single assembly or in assemblies arranged in parallel agree with each other as well as with such data for liquid-metal boiling in tubes.

This ISTC project proposal was prepared 10 years ago and was put in status 3 by the GB. Its costs were 700000 USD; the planned duration is 3 years.

**Topic #30:** Sodium boiling stabilization - Current work for French SFR and needs

Ch.Journeau (CEA) presented the French activities on “Fast reactor self protection under unprotected loss of flow (ULOF) and sodium boiling conditions” (prepared by D.Juhel and J.M.Seiler). The severe accident issues of SFR are similar to LWR plus a re-criticality risk. ULOF normally leads to Na boiling, flow excursion, voiding of fissile zone and transient over power. There exist different stages of boiling during slow flow transients (pump excursion): hot spot boiling, sub-cooled localized boiling and saturated generalized boiling.

Future needs in this research area are: to demonstrate the stability for reactor size conditions, to analyse effects of LOF transients on boiling stability and to analyse effects of dynamic instabilities on flow stability. New tests should result in complementary information to existing data. CEA has in principle an interest in additional, new tests but would like to discuss details of test arrangements.

It was decided to send a list of CEA publications to A.Sorokin.

**Partner-type ISTC projects**

**Topic #31:** Results of the ISTC project #3837-P "Liquidus Temperature Measurement of Ex-Vessel Corium" (LITEC); financed by CEA

S.Bechta (RIT-NITI) presented the results of the project LITEC. The ultimate goal of the LITEC project is to enhance the safety of NPP at the ex-vessel phase of a severe reactor accident. The project objective is the determination of the liquidus temperature of a prototypic multi-component ex-vessel corium of interest of the LITEC partner – CEA.

Pre-test thermodynamic modelling of this corium composition by the GEMINI-2 code and NUCLEA07 database was done. The modelling results indicated pre-test Tliq and Tsol values as well as the miscibility gap for the studied composition.

In order to determine experimentally the liquidus temperature the system was subjected to the differential thermal analysis (DTA), for which both powder and pre-molten samples were prepared. Subsequently it was found that the DTA was not applicable to the specified composition, therefore, alternative methods were used: visual polythermal analysis in a cold crucible (VPA IMCC), visual polythermal analysis in the Galakhov micro furnace, and visual polythermal analysis in high-temperature microscope. The solidus temperature was also determined by VPA in the high-temperature microscope.

The measured liquidus temperature of the examined corium corresponds well to the thermodynamic prognosis but the experimental determined value of the solidus temperature is higher than the calculated one. To check the liquid immiscibility, experiments were conducted with corium annealing, melting, exposition and rapid quenching in small molybdenum crucibles in the Galakhov micro furnace. The results indicated a single phase liquid above the liquidus temperature of the corium.

**Topic #32:** Results of the ISTC project #3078- P "Development of a Data Base for Thermo-Physical Properties of Corium"; financed by CEA

V.Strizhov (IBRAE RAS) presented the objective of the ISTC project that is to develop the database for the corium properties formed during a core melt-down accident in Nuclear power plants. The project focused on the review and assessments of thermo-physical properties of pure components and most important mixtures formed during different stages of the accident progression. The list of pure components included the following species both metallic and oxide: U, UO2, U3O8, U4O9, Ni, NiO, Zr, ZrO2, Fe, Cr, Cr2O3, FeOx, Fe2O3, Fe3O4, Al2O3, CaO, MgO, SiO2, HfO2, CeO2.

The scope of work included two tasks: Task 1) The critical assessment of existing experimental data on thermo-physical properties for pure species, identification of the lack of experimental data of major importance for solid and liquid states and development of recommendations for data assessment. 2) The compilation and critical review of existing experimental data on the thermo-physical properties for relevant pure components and corium and core-concrete mixtures formed during the accident progression. For the pure components the compilation of experimental data was performed showed that for solid phase conditions the properties had been measured for majority of components, however, for liquid phase conditions the amount of available data was rather limited. For each pure substance analytical expressions were chosen for each property (density; heat conductivity and thermal diffusivity; total emissivity; viscosity; surface tension).

Under Task 2 the compilation of experimental data and analysis for thermo-physical properties has been performed for three types of mixtures: a) corium mixtures, b) slags and lavas, and c) molten corium – concrete mixtures. These data were accompanied by the correlations used for their description. Based on these correlations and analysis of experimental data the recommendations for each mixture and each property were prepared. It must be noted that the SOKRAT code Material Properties data base uses the results of this partner project.

**Topic #33**: Next CEG-SAM meetings in March 2010 in Madrid, Spain

The 17th CEG-SAM meeting will be kindly organized by L. Herranz (CIEMAT) in Madrid March 29-31, 2010. The chairman M.Hugon thanked CIEMAT for its co-operation and support in advance.

The 18th CEG-SAM meeting will take place in St.Petersburg, September 28-30, 2010. S.Bechta (RIT-NITI) kindly offered to host the meeting.

M.Hugon thanked once more M.Veshchunov (IBRAE RAS) for the organization of the 16th CEG-SAM meeting in Moscow. He also expressed his thanks to all speakers and participants for their engagement at the meeting.

**Restricted session** (continued)

**Topic #34:** SARNET and CEG-SAM comments on ISTC & STCU proposals

D.Bottomley (JRC-ITU) and G.Pretzsch (GRS) reviewed critically the STCU project proposal #4758 and sent their comments to V.Krasnov (ISP NPP) to revise the proposal. D.Bottomley (JRC-ITU), Ch.Journeau (CEA), M.Krause (AECL) and G.Pretzsch (GRS) were asked to prepare an advice for the STCU project proposal #4758 (action 16/2). The STCU project proposal #4758 is not yet approved by the government. The subject of possible re-criticality of fuel-containing material accumulations in the Chernobyl NPP Unit4 is of generic interest. Further research in this area is important and therefore necessary to obtain as many results as possible for code validation purposes.

The ISTC project #3919 VERONIKA has been discussed several times by the CEG-SAM since it is of great interest. But, there are many difficulties to overcome in order to start this project. Beside the high costs and internal critical discussions within RIIAR in Dimitrovgrad, the new export control regulations will probably forbid the project since the results will be sensitive (experiments with enriched nuclear material).

The ISTC project #3936 PARAMETER-SF5,+-SF6 with boron carbide absorber rods is also of great interest for the CEG-SAM and will therefore be supported. The advice #20 for the ISTC project # 3936 (PARAMETER-SF5, -SF6) should be added to the official list of advices (action #16/3). At the last GB meeting it received the status “3”, accepted without funding.

Concerning the ISTC project proposal #1411 on liquid metal cooled fast reactors it was decided that CEA will discuss with partners the future activities in this research area.

**Topic #35:** Detailed discussion of presented ISTC and STCU project proposals and preparation of specific CEG-SAM advices

Once more a general discussion took place on future funding models for ISTC projects. One possibility could be co-funding of projects by several sources, for example, Russian partner(s) institutions, EU institutions and ISTC. Funded project without ISTC financial support will cause fewer problems by export control measures, intellectual properties and proliferation.

W.Gudowski mentioned that ISTC projects in the order of about 300k$ or less may have a greater chance to be accepted and supported by the GB. Project development grants are not a guarantee to a further financial support of the project.

**Topic #36:** Discussion of various actions

See specific action list (Annex #3).

**Topic #37:** Other matters; Final remarks

The chairman M.Hugon thanked once more IBRAE for hosting the meeting and for all its related excellent efforts and he thanked also the participants for their efficient work and contributions and wished them a safe journey back home.

**M. Hugon** (chairman) **P.Hofmann** (secretary)

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**Annexes:**

1. Revised final agenda of the 16th CEG-SAM meeting
2. List of participants at the 16th CEG-SAM meeting
3. Specific action list (appended below)
4. Minutes of the specialist’s meeting on the MCCI project #3831 (Ch.Journeau)

**Annex #3:**

**Action List**

16th CEG-SAM meeting; Moscow, Russian Federation, September 8 to 9, 2009

**Action 16/1**: All ISTC/STCU project coordinators / collaborators should make a list of their joint open publications with the collaborators published in peer-reviewed international journals and/or conferences and send it to the CEG-SAM secretary, A. Miassoedov and J. Stuckert. The publications should be stored in the ISTC/CEG-SAM webpage by a link to the corresponding projects.

**Action 16/2**: D. Bottomley (JRC-ITU), Ch. Journeau (CEA), M.Krause (AECL) and G. Pretzsch (GRS) should prepare an advice for the STCU project proposal #4758 on “Natural and calculation-experimental research of processes of fuel melt interaction with construction materials for severe radiation accidents on nuclear power plants”

**Action 16/3**: P. Hofmann will add the advice #20 for the ISTC project # 3936 on “Study of fuel assemblies with boron carbide absorber rods under severe accident conditions in the PARAMETER-SF tests series; SF-5/SF-6” to the official advice list of the CEG-SAM.

**Action 16/4**: D. Bottomley (JRC-ITU), Ch. Journeau (CEA) and M. Krause (AECL) will contact V. Kornyeyeva (NFC KIPT) to explore the possibility of the execution of specific material interaction experiments at high temperatures in the Ukraine.

**Action 16/5**: J. Stuckert (FZK) will prepare a list of publications on chemical interaction experiments with core materials at high temperatures performed within the European research community. The list should be sent to V. Kornyeyeva (NFC KIPT) for her information and to the secretary.

**Action 16/6**: Ch. Journeau (CEA) will discuss possible activities in the research area of the ISTC project proposal # 1411 on “Experimental and numerical study of liquid metal boiling as simulation of accidents in fast reactor core” with interested colleagues within CEA. The outcome should be presented at the 17th CEG-SAM meeting.

**Action 16/7**: V. Loktionov (MPEI), coordinator of ISTC project #3635 “Scale experimental investigation of the thermal and structural integrity of the VVER pressure vessel Lower Head in severe accidents”, will discuss the remaining research activities of his project with L.Nicolas (CEA).

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**Annex #4**:

**Specialist’s Meeting at ISTC Headquarters on the MCCI project (#3831)**

Ch.Journeau, CEA

After thanking the ISTC for their warm welcome, Ch. Journeau presented the current work on the Molten Core Concrete Interaction being launched within the European Severe Accident research Network of Excellence. Particulars of the MCCI experiments (especially VULCANO – 40 kg prototypic corium with induction sustained heating - and MOCKA – several tons of aluminothermite, chemical heating – have been presented, as well as the objectives, from the SARNET point of view of a large scale experiment.

Then, the VNIIEF team (A. Kondrashenko, A. Blikov and V. Peshkov) have presented in thorough details the already performed test and the plans for the next two tests. A video of the 1st preliminary test has been presented (in the kind presence of ISTC Director) and discussed:

A ∅25, 16cm high cavity (roughly the same volume as for VULCANO VB tests) has been made in a concrete cylindrical test section (The concrete composition is similar to the limestone-rich concrete used for VULCANO VB-U6 and VBS-U1 tests). The pyrotechnic powders (based on Zr and Fe2O3) are manually installed in the concrete cavity. An electrical igniter is positioned at the top center of the powders. 3 propane-gas burners have been installed on the top of the crucible (to counter surface heat losses and soften the surface for briquette drops). Their performances have been previously assessed with a test in an empty gypsum crucible having the same geometry. One 135 g briquette had been made (by cold pressing since its ignition temperature is around 600-700°C). In the subsequent tests, it is generate the sustained heat by introducing large metal foil-wrapped 1-kg briquettes every 5-10 s through a 15 m high inclined chute. A. Kondrashenko indicated that he estimated that the briquette would stay only 0.1 s in the flame, so that there should be no risks of premature exothermal reaction.

The ignition proceeded well and a 3 kg melt has been obtained. Large bubbling was observed in the first 10 s. Great mixing was visible at the surface. The briquette was manually lowered in the pool and dissolved. After some time, the gas burner was set on and a significant of the crust-covered area was visible on the surface, which should favour briquette insertion. One half of the ingot was shown to the participants. A thin (~2-3 mm) metallic layer was found at the bottom, while metal droplets were also visible in the oxide layer.

Discussions have been also conducted on the best way to install thermocouples and to calibrate the VNIIEF-made 4-channel pyrometer (e.g. by assessing the effect of a flame between sensor and calibration W lamp).

The second test, to be performed soon, will assess the briquette introduction, firstly in an empty cavity model (to study the briquette trajectories), then with about 8 (start of experiment) to 30 kg (end of test) in a ∅25 x 34cm cavity. The briquette introduction is planned to last about 4 minutes.

The medium scale test is planned in October. The corium mass would be from 35 to 100 kg in a ∅35-40 x 50-60cm cylindrical cavity. The sustained heating is expected to last 10-12 minutes.

A meeting is planned in Sarov after this test. The following program has been set:

Departure from Moscow (Kazan train station) on Monday 23 November 2009, evening.

Arrival in Sarov on Tuesday 24 morning.

24-25 November: visit of the facility, meeting with VNIIEF specialists, visit of the Atomic museum and of the monastery.

Wednesday 25 November evening: night train top Moscow

Thursday 26 November: Arrival in Moscow Kazan station.

ISTC will take care of the train reservations, VNIIEF of the accommodation in Sarov.

C. Journeau will transmit to VNIIEF before 15 September the final list of Western participant data for the visa request and close city authorisation procedure. The help of ISTC is also requested to ease these administrative matters.

In the case the experiments are successful, there will be a technical interest in launching the second phase of this project. (Due to its great technological originality, the CEG SAM had advised that EC funded a first preliminary phase (this project 3831) to prove the test feasibility before launching the large scale test).

Since the start of the discussions between CEGSAM and VNIIEF, the EU funding of ISTC project has drastically declined. Therefore, if this project is to be run, alternative funding schemes must be found. The idea of cost sharing (~1/3rd taken in charge by the Russian part, 1/3rd paid by the EU, 1/3rd paid by some Western research organisation has been evoked. All parts indicated that such a scheme will have to be thoroughly discussed with their management before a solution can be found.

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